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THE EVOLUTION AND BREAKDOWN OF A WAVE PACKET

PROPAGATING IN A LAMINAR BOUNDARY LAYER

Progress Report for period 1 April 1982-March 1983

Final

Agreement No. XR Aero/253/01

AFOSR ~~Grant No.~~ 82-0272

and AUWE P226 (RF79/82)

The programme of work contained in the proposal covered a number of associated topics concerned with the evolution of instability waves in laminar flows, their subsequent amplification and their eventual breakdown into turbulence. Initial emphasis was placed on the non-linear growth of wave packets, following the observation that marked non-linear behaviour occurred at surprisingly low signal levels. The Reynolds stresses controlling these events arise mainly from the modulation envelope of the wavetrain, and are consequently important in the types of deeply modulated wavetrain that are generated naturally by free-stream turbulence. It is intended to document this behaviour so that quantitative assessments can be made. Although the data collection phase is quite straightforward the necessary graphical display routines are only now available on the PDP 11/44. In previous work of this type the data was processed on KDF9, and the graphical output system on that machine was used to generate the necessary contouring and perspective displays. The NPL graphical package has now been successfully implemented on the PDP 11. Far more time and effort than had been initially envisaged, was however needed to write the machine dependent portion of the code concerned with output etc., as well as the device drivers for our own plotters. However, now we are able to produce graphical displays on VDU's with a hard copy facility, various flat-bed

pen plotters, as well as on the high resolution NPL plotters and laser scan unit via magnetic tape. The routines are all called as Fortran subroutines.

While the graphics package was being developed experimental effort was directed to the problem of "side-band" instability where noise excitation from the background turbulence is able to amplify in the presence of a large amplitude sine wave. In this series of experiments the behaviour of different spectral bands has been measured in the presence of artificially excited periodic wave trains of different amplitudes. Data in binary form is acquired by the A/D linked to the micro-computer system and then written in blocks of 1024 bytes to 9-track digital tape. This date can then be read and processed in various ways on the PDP 11. Mostly the development of the power spectra of the hot-wire sigral have been examined. Typically 128 K samples are required for each power structum to provide reasonably stable estimates. Many hundreds of such spectra have been processed and the various cross-plots and displays are now being produced. Non-linear features of the signals have been brought out through auto-bispectral density plots which provide a measure of the various wave-wave interactions that occur. Phase plane displays of some of the signals have also been obtained in the expectation that patterns similar to those associated with strange attractor models would appear. More work is needed in this area.

Further experiments with the addition of controlled excitation noise are in progress. The data processing and display routines developed for the pure periodic excitation can be used directly, and this portion of the work will be a straightforward extension of that work.

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The final part of this programme involving the cross-bispectral transfer function has yet to be attempted. The data for this exercise involves both sampling the noise excitation and the output signal simultaneously. A 2-channel A/D collection system will have to be written before this is carried out.

Before embarking on the serious collection of data a careful survey of the mean flow boundary layer flow was undertaken. This involved measuring the velocity profiles at a large number of locations both across the span of the plate and at different distances from the leading edge. It was found that the measured profile shapes conformed closely to the theoretical Blasius flat plate solution, but the thickness was generally slightly less than the prediction. The discrepancy was roughly about 1% with a scatter of around 1/2 %. No explanation for the lower measured boundary layer thickness is offered. It was also noted that the thickness varied across the span; the degree of the variation increased with distance from the leading edge but the pattern seemed to be fixed. The non-uniformity, which was presumedly created by the last screen, was hardly more than the scatter at an R_{δ^*} of 1380, but the magnitude of the variation increased to about 1% at an R_{δ^*} of 2200. The spanwise variations are a little smaller than those observed by Klebanoff in his low turbulence tunnel at N.B.S.

The main effort on the theoretical front has been put on the question of the "receptivity" of the laminar boundary layer to free-stream disturbances. An attempt has been made to understand the physics involved in the process so as to be able to predict the magnitude of the excited Tollmien-Schlichting waves in a given free-stream environment. Although theoretical work on this topic was already in hand the effort was slight. However, Professor H Salwen

visited the NMI for some 6 weeks in the Summer of 1982, and the ensuing discussions acted as a very powerful stimulus. He is working on the same problem with the group in the US at NASA Langley. His theoretical model describes the way free-stream vorticity is fed into the boundary layer through the stagnation region at the nose of an aerofoil or body. The leading edge modal solution will match onto an appropriate Tollmien-Schlichting wave that then develops downstream according to linear stability theory. Initially the amplitude of this travelling wave will decay as it propagates downstream up to the critical Reynolds number, and then it will amplify. Far downstream the amplitude will be linked to the matching process. In my work the downstream travelling wave arises directly from the coupling of the frozen free-stream vorticity in the outer flow with the wave motion in the boundary layer. Because the equations describing the perturbations in the boundary layer are partial there is a weak coupling between the Orr-Sommerfeld modes, and thus a large continuous spectrum (the free-stream vorticity) can excite Tollmien-Schlichting waves. The coupling only arises through the slow growth of the boundary layer. Using the method of steepest descent to arrive at a solution for downstream we find that the wave train appears to emanate from the point where the amplification is zero, and the algebraic coefficient - or receptivity - is defined by various integrals across the boundary layer involving the eigenfunction and its adjoint. The numerical computations have not yet been carried out. To pursue this topic a good Orr-Sommerfeld solver was required. Previous programs on KDF9 written in K-Autocode are no longer available and so a new program, based on Davey's compound matrix method, has been written and fully tested.

Future Work Programme

(i) Complete the experimental and data processing on periodic excitation with added noise.

(ii) Collect both input and output signals for the case of noise excitation.

(iii) Compute the bispectral transfer functions.

(iv) Collect and process data for pulsed excitation at different amplitudes.

(v) Use bispectral transfer function to compute response from various excitations, such as (iv), and compare with the experiment.

(vi) Compute receptivity from free-stream turbulence.

Publications

(i) Estimates of the Errors Incurred in Various Asymptotic Representations of Wave-Packets.
J Fluid Mech. 1982, vol 121, pp 365.

(ii) The Evolution of Two-Dimensional Wave Packets in a Growing Boundary Layer.
Proc. Roy. Soc. 1982, A 384, 317.

Related Work supported by AFOSR

Large Scale Structures in a Forced Turbulent Mixing Layer

by M Gaster, E. Kit* and I. Wygnanski*.

Submitted to J. Fluid Mech.

*University of Tel Aviv.

Also research on compliant surfaces supported by AUWE (Portland)

A Numerical Investigation into Boundary-Layer Stability on Compliant Surfaces.

by P W Carpenter*, M Gaster and G J K Willis to be given at a Conference on "Numerical Methods in Laminar and Turbulent Flow", Seattle, August 1983.

*University of Exeter.

COST ESTIMATE (APRIL 1983 - MARCH 1984)

FUNDING AGENCY:	AFOSR £	AUWE £	RAE £	DOI £	TOTAL £
1. Salaries					
Principal Investigator Dr M Gaster: 110 days					
Scientific Officer: 110 days					
(Total Direct Salary £18,500)	16,200	16,200	16,200	16,200	64,800
2. Expendable Materials	250	250	250	250	1,000
3. Travel One visit to USA	1,000	-	-	-	-
Other travel & subsistence	-	200	200	200	1,600
4. Facility Charges: Inclusive of compute usage on year round basis - 50 days ％ £152 per day	1,900	1,900	1,900	1,900	7,600
TOTALS:	£19,350	18,550	18,550	18,550	75,000

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